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3. Friction Stir Welding: Processes and Recent Developments

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ABSTRACT

Improved weld integrity, reduced upper-plate thinning, and faster welding speeds are some of the most notable outcomes of recent advances in friction-stir welding tool and process improvements. Induction heat, laser heat, resistance heat, arc heat, radiation, and ultrasonic vibrations are all forms of external energy. When using energy-assisted FSW, significant benefits such as extended process window, improved process parameters and mechanical properties, reduced load and tool wear have been observed. Because of its efficiency and sustainability, friction stir welding (FSW) has a wide range of applications in a variety of industries. Furthermore, the development attempted to address the issue of non-uniformity in temperature distribution in weld zone pinholes left over from the welding process in FSW. More effort should be put into modelling the FSW process. At the moment, the available models make several dubious assumptions. Finally, efforts have been made to forecast FSW's future and provide some guidance for future developments. Friction Stir Welding Processes and Recent Developments will be discussed in this paper.

KEYWORDS:

Friction Stir Welding, Processes, Developments, Heat, Laser Heat, Process Parameters, Mechanical Properties, Welding Aluminum, Join Polymers, Solid-State..

Introduction:

It is a method of joining materials without the use of heat. The process, as the name implies, uses friction energy to weld two materials together by softening their surfaces and allowing them to traverse. [1]

The following materials can be used in friction stir welding:

It was originally developed for welding aluminium and is now primarily used in industries to join aluminium alloys as well as magnesium, titanium, copper, zinc, and steel.

Recently, successful experiments have shown that this technique can be used to join polymers. Aluminium alloys, copper alloys, titanium alloys, mild steel, stainless steel, and magnesium alloys can all be joined using FSW. It has recently been used successfully in polymer welding.

FSW has also recently achieved the joining of dissimilar metals, such as aluminium to magnesium alloys. FSW is used in modern shipbuilding, railroads, and aerospace applications. In theory, this process should be able to weld any material that can be hot worked. [2]

Manufacturing industries are investing heavily in the development of sustainable (cost-effective, energy-efficient, and environmentally friendly) processes. Friction stir welding (FSW) technology is one such sustainable manufacturing process that has emerged as a viable alternative to a number of traditional welding processes.

FSW is a solid-state welding process that was designed to join difficult-to-weld materials. Without the use of a filler material, a solid-state welding process uses plastic deformation to form metallurgical bonds. The process temperature is less than the melting point of the joined materials.

Benefits of FSW:

The advantages of FSW are significant in the welding process. Only degreasing is required for FSW joint preparation between two plates. It provides high welding quality with increased tensile strength, exceptional fatigue properties, and corrosion resistance from oxidation and chemical action. It is a low-cost method of welding with no consumables and low energy consumption, as opposed to the arc welding process, which consumes electrodes.

When compared to arc welding (or) gas welding, FSW is one of the most environmentally friendly because there is no arc, fumes, or spotter during the process. It does not require shielding gas or surface cleaning after the welding process to continue operations. [3]

The metallurgical benefits of friction stir welding are that this process is carried over solid phase. It has low workpiece distortion under external stress during machining. This welding is the path constraint, resulting in good dimensional stability and repeatability with fine microstructure.

The two contacting surfaces of the base material (BM) are brought into contact with each other and clamped using strong fixtures to restrict their movement during plunging of a rotating FSW tool in a typical butt joint welding. During plunging, a large axial force is applied by a non-consumable rotating tool as it comes into contact with the joint line.

The tool, which has a specially designed shoulder and a pin/probe, is inserted into the sheets' abutting edges and rotated for a few seconds to plasticize the workpiece material. The tool is then moved towards the weld, with the shoulder enclosing the plasticized material. To prevent sticking during welding, a base plate is placed between the workpiece and the anvil.

This method employs a non-consumable rotating third body to generate frictional heat and forge continuous solid-state joints. After that, the properties of these friction stir welds are discussed and compared to those of the base metal and comparable GTAW welds. The effects of section thickness on FSW are then discussed.

Friction stir welds on aluminium alloys with thicknesses ranging from 2 to 30 mm are demonstrated. A brief description of efforts to friction stir weld various other materials follows. Thermal stability of the tool is defined as a critical process characteristic.

Friction stir welding (FSW) is a solid-state process that joins two objects at temperatures below their critical temperature. Since TWI, The Welding Institute, invented and developed the technology in 1991, FSW has grown rapidly. The FSW is distinguished by its ability to join materials without reaching their fusion temperature. Initially, FSW was used on aluminium alloys because it welds easily due to the alloys' low softening temperatures. Magnesium alloys have the potential to replace aluminium alloys in many structural applications due to their unique properties such as low density and high strength to weight ratio. [4]

Process Parameters:

The FSW should be used to control four major process parameters: down force, welding speed, the rotation speed of the welding tool, and tilting angle. These four parameters must be mastered in order for FSW to be suitable for mechanised welding. For variations in weld outcome, various parameters must be investigated. Down force, welding speed, welding tool rotation speed, and tilting angle are all process parameters that influence the mechanical properties and hardness of the welded material. Different parameters have different effects on welded material. The effects of this parameter are frictional heat, stirring, material mixing, and oxide layer breaking, tilting angle produces the appearance of the weld and thinning, and welding speed produces Appearance and heat control, as well as downforce, generate frictional heat while maintaining contact conditions. [5]

Review of Literature:

Buffa et al. proposed a 3D coupled thermomechanical analysis using the DEFORM-3D package to simulate FSW. The work piece is regarded as a rigid viscoelastic material, and the Lagrange incremental technique is employed. They simulated the FSW process in two stages: plunging and welding. The flow stress material model is a function of temperature, strain, and strain rate. To avoid contact instabilities between abutting edges, two sheets of work pieces are treated as a single block. The strain plot is nonsymmetric, with greater strain on the advancing side, whereas the temperature distribution is almost symmetric.

They predicted the material flow to be nonsymmetric using the particle tracking method in simulation. [6]

Rhodes et al. conducted an experimental study to investigate the impact of the welding process on weld nugget (WN), heat affected zone (HAZ), and microstructural changes in FS Wed 7075 aluminium alloy material.

According to the study, the friction stir welding process was useful for joining unwieldy aluminium alloys without introducing a cast microstructure, and it had little effect on the WN, HAZ, and microstructure of the welded joint when compared to fusion welding techniques. [7]

Kaushik conducted an experimental study to investigate the effects of the FSW process on the microstructure and mechanical properties of a cast composite matrix AA6063 reinforced with 7% Sic particles. According to the study, FSW had an effect on the growth, dissolution, and reprecipitation of hardening precipitates during welding. Mechanical properties of friction stir welded joints such as ultimate tensile strength, percentage elongation, and hardness improved as a result of microstructural changes that occurred during the FSW process. [8]

Objectives:

- The FSW unit will be developed solely for research purposes.
- Investigate and create criteria for describing the welding process and basic procedure.
- Creation of a tool tip capable of performing a friction stir weld.

Research Methodology:

This study's overall design was exploratory. Future research will further the science of FSW by increasing our understanding of the complex physical interactions that underpin a process that began as a technology. This review focuses on the process's fundamental understanding and its metallurgical implications. The emphasis is on heat generation, heat transfer, and plastic flow during welding, as well as aspects of tool design, defect formation, and the structure and properties of welded materials. The tandem and staggered Twin-stirTM variants are expected to further fragment and disperse tenacious residual oxides within the weld region or a portion of the weld region, respectively. This will result in better weld integrity and performance. Furthermore, for both butt and lap joints, the staggered Twin-stirTM method is likely to provide an advantage and, in some cases, be preferred. [9]

Result and Discussion:

Friction stir welding generates frictional heat by rotating a tool known as a "shoulder" along the joint of the various components.

A pin at the shoulder's end approximates the thickness of the workpiece.

The pin is moved along the joint line, causing the material to melt and merge precisely.

Meanwhile, the shoulder remains in contact with the workpiece's top surface to prevent the softened material from spilling out.

The metal sheets cool almost instantly due to the low temperature inherent in the welding process, freezing in a new merged solid state. [10]

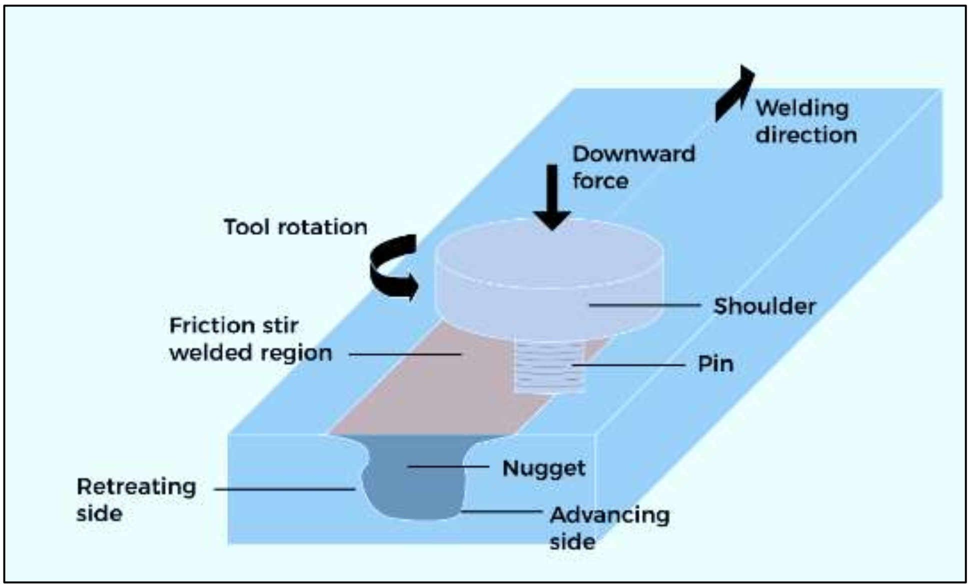

Figure 1: Friction stir welding generates frictional heat using a rotating tool known as a "shoulder", which runs along the joint of the different components.

Friction stir welding is done with a rotating cylindrical tool that has a profiled pin (also known as a probe) with a diameter smaller than its shoulder. The tool is fed into a butt joint between two clamped workpieces during welding until the probe pierces the workpiece and its shoulder touches the surface of the workpieces. The probe is slightly shorter than the required weld depth, with the tool shoulder resting on top of the work surface. After a brief pause, the tool is advanced along the joint line at the predetermined welding speed.

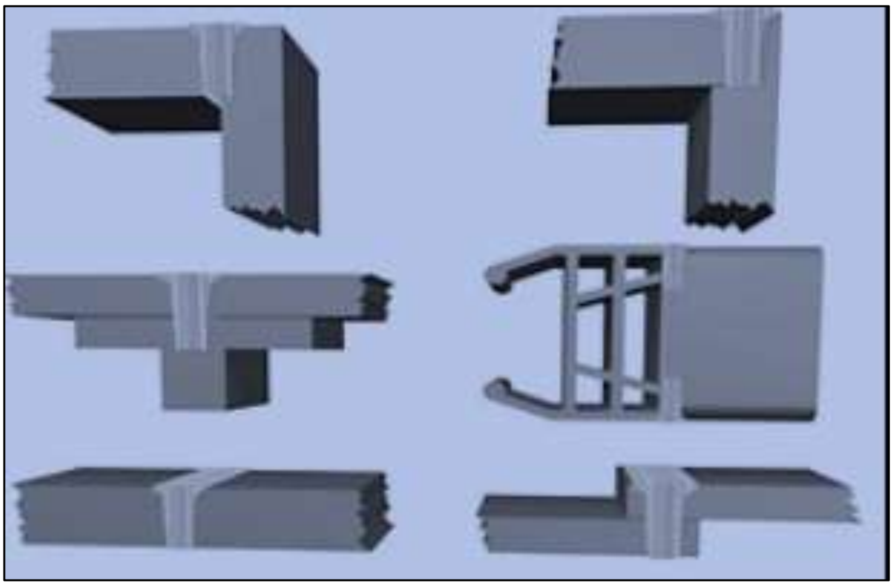

Figure 2: Joint Designs

Frictional heat is generated between the work pieces and the wear-resistant tool. This heat, combined with the heat generated by the mechanical mixing process and the adiabatic heat within the material, causes the stirred materials to soften but not melt. As the tool advances, a special profile on the probe forces plasticized material from the leading face to the rear, where high forces aid in forged weld consolidation. The tool traversing the weld line in a plasticized tubular shaft of metal causes severe solid-state deformation involving dynamic recrystallization of the base material. [11]

Friction stir welding (FSW) is a hot-shear solid-state joining process in which a rotating tool with a shoulder and a threaded pin moves along the butting surfaces of two rigidly clamped plates placed on a backing plate, as shown in Figure. The shoulder makes firm contact with the workpiece's top surface. Heat generated by friction at the shoulder, and to a lesser extent at the pin surface, softens the weld material. As the tool is translated along the welding direction, severe plastic deformation and flow of this plasticized metal occurs. Material is moved from the tool's front edge to the trailing edge, where it is forged into a joint. Although Figure depicts a butt joint for illustration purposes, FSW can also fabricate lap joints and fillet joints.

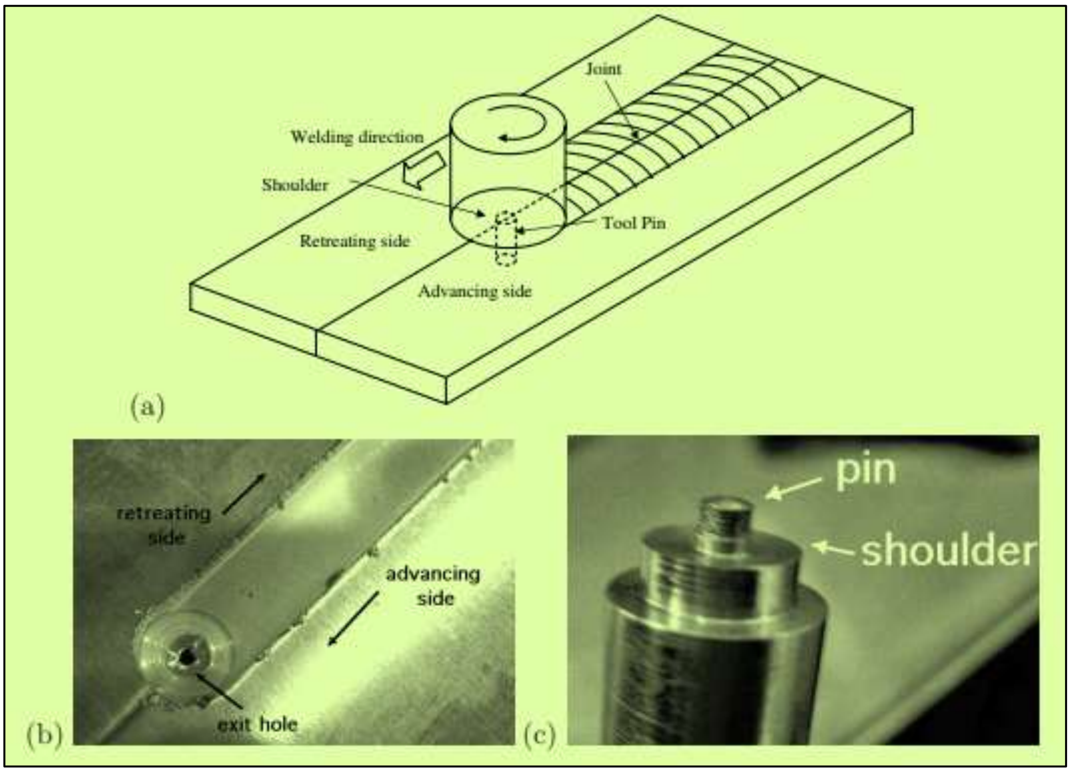

Figure 3: (a) Schematic illustration of the friction stir welding process. (b) An FSW weld between aluminum sheets. (c) An actual tool, with a threaded-pin.

The advancing side is the half-plate whose rotational direction is the same as the welding direction, while the retreating side is the opposite. This difference can cause asymmetry in heat transfer, material flow, and the properties of the two sides of the weld; for example, the hardness of certain age-hardened aluminium alloys tends to be lower in the heat-affected zone on the retreating side, which then becomes the location of tensile fracture in cross-weld tests; pure titanium is the same. [12]

Variables in the Process and Their Impact Process variables are critical in producing a good weld. As a result, it is critical to comprehend the process variables and their effects on the process. As shown in the table, process variables can be divided into three categories.

Process variables: Choosing the right combination of process parameters is critical because they have a wide range of effects on output variables such as temperature and material flow behaviour. Heat generation is proportional to the tool's rotational speed. As rotational speed increases, so does the relative velocity between tool and work piece, and thus frictional heat input. Welding velocity, on the other hand, has an inverse effect on heat generation.

Dimension and geometry of the tool shoulder and pin are critical design parameters in the defect-free FSW process. Maximum shoulder diameter is important because increased heat generation can cause a loss of traction between the work piece and the tool, resulting in improper material mixing due to slippage.

On the other hand, lower heat generation may not properly soften the work piece. Depending on the welding requirements, shoulder geometry can be flat, concave, or convex. Because of its geometry, the concave shoulder contains viscous material better than the other two, resulting in less ribbon formation, but the contact area is reduced. Concavity of 5°-20° is usually considered.

Table 1: Process variables in FSW process

Process variables	Design variables	Material parameters
Tool rotational speed	Pin geometry and its dimension	Tool material
Welding speed	Shoulder geometry and its dimension	Work piece material
Tool tilt angle	Joint configuration	Back up material
Plunge depth		

Material parameters: Heat loss occurs between the tool and the work piece, which greatly influences weld quality. The anvil material (backing plate) should be rigid enough to provide adequate reaction force, and the work piece material should not stick to the anvil material; otherwise, the weld quality will suffer.

The adaptation of the friction stir welding process (FSW) to materials with thicknesses of 1000m or less is known as micro friction stir welding (FSW). MSFW's ability to join a wide range of materials without the use of fluxes, shielding gases, or post-weld cleaning can greatly benefit applications such as thin-walled structures, electrical, electronic, and micro-mechanical assemblies.

It is particularly useful for fusing dissimilar materials. Downscaling to achieve FSW, on the other hand, presents some significant challenges.

Figure summarises the concept of friction stirs welding (FSW), which was invented and developed by Wayne Thomas and colleagues at TWI and is now a widely used and successful technology capable of welding a wide range of materials and sections.

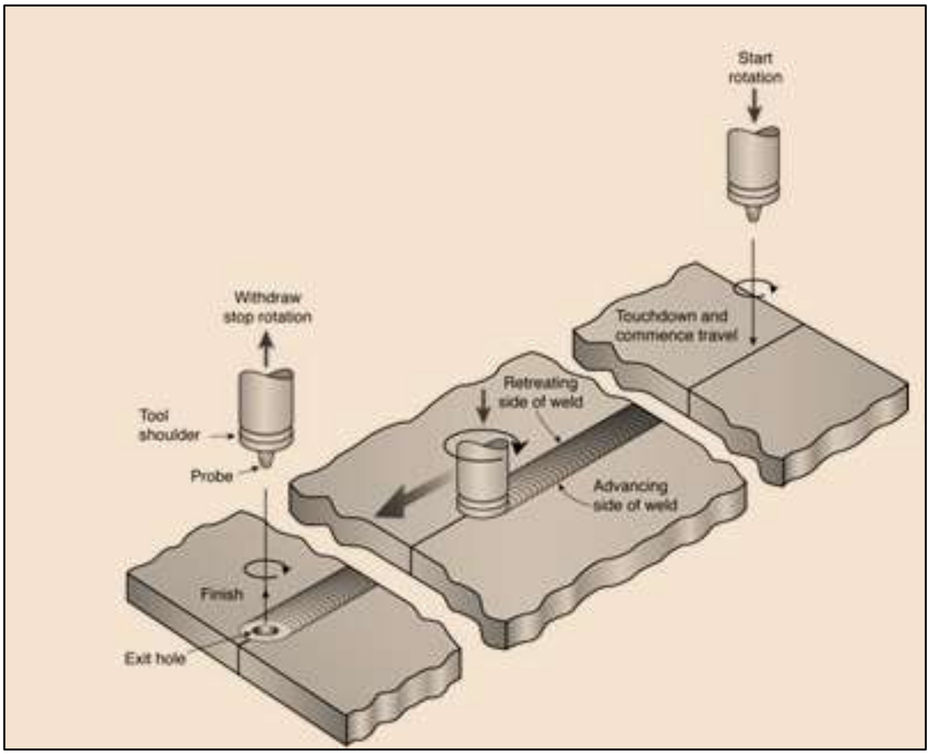

Figure 4: Schematic of the friction stir welding process.

Friction stir welding (FSW) has undergone systematic development, resulting in a number of variants of the technology. The following describes preliminary research on three-dimensional material processing techniques such as Twin stirTM, Skew-stirTM, Re-stirTM, Dual-rotation stir, and Pro-stirTM.

FSW is primarily used to join aluminium alloys in the shipbuilding and marine industries, aerospace, automotive, and rail industries. Furthermore, the technology benefits the aluminium extrusion industry significantly.

The technique is already being used by automotive suppliers for wheel rims and suspension arms. Fuel tanks welded by FSW have already been launched in spacecraft, and many other space advancements are in the works; commercial jets welded by FSW have successfully completed flight trials, with high volume commercial production on the horizon.

Aluminium panels for high-speed ferries and rail vehicles are also manufactured. Furthermore, friction stir welding of 50 mm thick copper material has provided a potential solution for radioactive waste nuclear encapsulation. Friction stir welding is making an impression as a material processing technique, and the prospects for successful FSW welding of steel products appear promising.

Twin-stir™ technique:

The idea was to use a pair of tools on opposite sides of the workpiece that were slightly displaced in the direction of travel. The contrarotating simultaneous double-sided operation with combined weld passes has several advantages, including reduced reactive torque, a more symmetrical weld, and increased heat input through the thickness. A similar arrangement with two rotating tools, one used to pre-heat and one to weld, has recently been reported. This disclosure, on the other hand, depicts a 'tandem' technique in which both tools rotate in the same direction. Tandem arrangements with tools rotating in the same direction are also mentioned (10). It is also disclosed how to use 'tandem' contra-rotating tools in-line with the welding direction and 'parallel' (side-by-side across the welding direction) tools.

Parallel twin-stir™:

The Twin-stirTM parallel contra-rotating variant allows lap welding defects to be positioned on the 'inside' between the two welds. The most significant flaw in low dynamic volume to static volume ratio probes using conventional rotary motion is 'plate thinning' on the retreating side. Hooks may be the most significant defect type with tool designs and motions designed to minimise plate thinning. For parallel overlap welding, the Twin-stirTM method may allow for a reduction in welding time.

Tandem twin-stir™:

All conventional FSW joints can benefit from the Twin-stirTM tandem contra-rotating variant, which reduces reactive torque. More importantly, the tandem technique will improve weld integrity by disrupting and fragmenting any residual oxide layer that remains within the first weld region using the following tool. Welds have already been produced using conventional rotary FSW, in which a second weld is made in the reverse direction over a previous weld with no mechanical property loss.

Staggered twin-stir™:

The staggered arrangement for Twin-stir™ means that an exceptionally wide 'common weld region' can be created. Essentially, the tools are positioned so that the second probe partially overlaps the previous weld region, with one in front and slightly to the side of the other. Because the geometry details at the extremes of the weld region are similar, this arrangement will be especially useful for lap welds, as the wide weld region produced will provide greater strength than a single pass weld. [13]

Conclusion:

Friction stir welding provides numerous benefits to the manufacturing industry across a wide range of applications. The basic process is well understood, has proven to be robust and reliable in operation, and there is an incentive to expand its use to more difficult applications and alternative materials. The principle of composite tools for welding high temperature materials has been demonstrated, and future advancements in this area are expected to broaden the use of FSW in joining steels, stainless steels, and nickel-based alloys. The formability of welded blanks is critical for various industrial applications, particularly in the automobile industry. In the second section, the FEM method is used to simulate the process. As a result, we can conclude that FSW is the most cost-effective and environmentally friendly welding process for industrial applications.

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